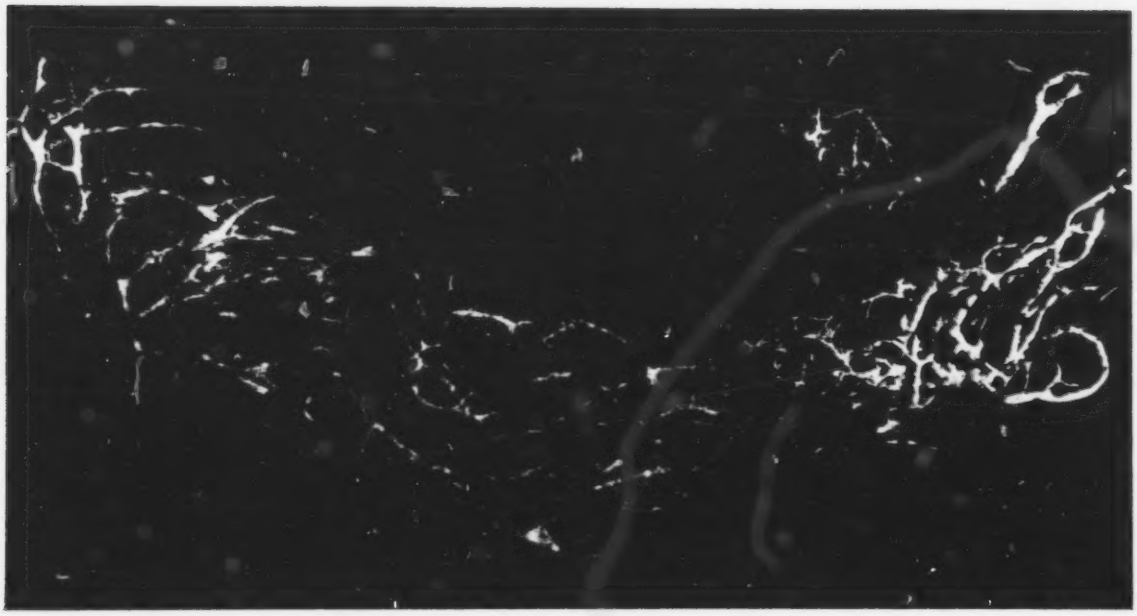
Environment Canada
Forestry Service

Environnement Canada
Service des Forêts

A quantitative study of epiphytic lichen vegetation in relation to SO_2 pollution in western Alberta

by A. C. Skorepa and D. H. Vitt



Information Report NOR-X-161
October 1976

northern forest research centre
edmonton, alberta

A QUANTITATIVE STUDY OF EPIPHYTIC LICHEN VEGETATION IN RELATION TO SO_2 POLLUTION IN WESTERN ALBERTA

BY

A.C. SKOREPA[1]

D.H. VITT[1]

INFORMATION REPORT NOR-X-161
OCTOBER 1976

NORTHERN FOREST RESEARCH CENTRE
CANADIAN FORESTRY SERVICE
ENVIRONMENT CANADA
5320 - 122 STREET
EDMONTON, ALBERTA, CANADA
T6H 3S5

[1] Department of Botany, The University of Alberta, Edmonton, Alberta, Canada, T6G 2E9

Skorepa, A.C. and D.H. Vitt. 1976. A quantitative study of epiphytic lichen vegetation in relation to SO_2 pollution in western Alberta. Environ. Can., Can. For. Serv., North. For. Res. Cent. Inf. Rep. NOR-X-161.

ABSTRACT

Lichens were studied on *Pinus contorta* var. *latifolia* around two recent sources of SO_2 pollution in the Rocky Mountain House area of west-central Alberta, Canada. A relative luxuriance-density index was developed to detect changes in the epiphytic lichen flora in an area where a lichen desert had not yet developed. The luxuriance-density values were more sensitive than the Index of Atmospheric Purity in illustrating recent changes in the flora. Analysis of the data by ordination and cluster analysis techniques distinguished four epiphytic lichen associations, three of them affected by the SO_2 pollution. After 3 years of exposure to the SO_2 pollution, the adjacent lichen flora has been greatly affected. *Alectoria glabra*, *Cetraria halei*, and *Usnea alpina*, all common components of the unaffected vegetation, are among the more sensitive species.

RESUME

Une étude des lichens sur *Pinus contorta* var. *latifolia* (Pin tordu latifolié) fut mené aux abords de deux nouvelles sources de pollution par le SO_2 dans la région du Rocky Mountain House dans le centre-ouest de l'Alberta, Canada. On a mis au point un indice de la densité de luxuriance relative, dans le but de détecter des changements chez la flore des lichens épiphytes dans un secteur où aucun désert de lichen ne s'est encore développé. Les valeurs de densité de luxuriance furent plus précises que l'Indice de pureté atmosphérique pour illustrer les changements récents chez la flore. Une analyse des données par ordinateur de même que des techniques d'analyse par grappes ont permis de distinguer quatre associations de lichens épiphytes, dont trois ayant subi la pollution causée par le SO_2. Après trois ans

d'exposition à la pollution du SO_2, la flore de lichens adjacente avait été gravement touchée. *Alectoria glabra*, *Cetraria halei* et *Usnea alpina*, toutes composantes communes de la végétation encore intacte comptent parmi les espèces les plus vulnérables.

CONTENTS

	Page
INTRODUCTION	1
Study Area	2
METHODS	3
Sampling	3
Data Processing	5
RESULTS	6
DISCUSSION	16
Comparison of IAP and LD Index	19
CONCLUSIONS	22
ACKNOWLEDGMENTS	24
LITERATURE CITED	25

INTRODUCTION

The sensitivity of lichens to air pollution was noted in Paris more than a century ago (Nylander 1866). During recent years, botanists have attempted to analyze lichen populations around major sources of pollution to find out how they are affected, and they have explored the possibility of using lichens as biological indicators of air pollution. Studies conducted in North America have included those by LeBlanc and DeSloover (1970); LeBlanc, Rao, and Comeau (1972); LeBlanc, Robitaille, and Rao (1974); Rao and LeBlanc (1967); Brodo (1966); Nash (1971, 1972); and Mathis and Tomlinson (1972). Numerous studies on the effects of air pollution on lichens have been conducted in Europe. Among these are Skye and Hallberg (1969); Fenton (1960, 1964); Gilbert (1965, 1970); and Hawksworth and Rose (1970). Ferry, Baddeley, and Hawksworth (1973) have summarized the literature.

The sensitivity of lichens to air pollution offers a unique opportunity to determine the relative purity of the air in a given area by observing the abundance or scarcity of lichens. This promoted Gilbert (1970) to suggest that people with respiratory disorders should try to live in areas having a rich lichen flora. There are other advantages in studying lichens in relation to air pollution: 1) a given lichen flora reflects the average, cumulative effects of air pollution over a long period of time, 2) observations of lichens supplement data from SO_2 monitoring devices, and 3) lichens show the effects of air pollution on living things.

Past studies of lichens in relation to air pollution have been conducted around long-established sources of pollution. The sources of pollution presumably have changed adjacent lands into "lichen deserts." These classic areas lend themselves nicely to the construction of distribution maps of certain species around a source of pollution, or to the formulation of zones of pollution based on the gradual appearance of certain species and the number of species in lichen communities at varying distances from a pollution source (Hawksworth and Rose 1970). DeSloover and

LeBlanc (1968) developed a statistic which they termed the Index of Atmospheric Purity (IAP), by which pollution zones can be mapped and certain species of lichens considered either sensitive or resistant to air pollution.

All of these techniques are of little or no value around a new source of pollution. The gas plants in our study area have been in full operation for only 3 yr. Lichens persist on trees 100 m from the plants, and although most species typical of the region are still present, their development is poor and their numbers are reduced. The IAP is not a useful index in this case because it does not consider density and luxuriance and because it requires a depauperate zone of severely reduced diversity to be meaningful. The method of defining pollution zones used by Hawksworth and Rose (1970) also assumes the presence of a lichen desert. In this method, increasingly less polluted zones or areas are characterized by the presence of certain species. For example, *Hypogymnia physodes* first appears in zone 4. This type of scale could be quite useful in quickly estimating the relative purity of the air in a given area by observing the lichens. It could be of greater value if more consideration of density and luxuriance of each species were given. The method is actually similar to the IAP technique but less descriptive or detailed.

The new pollution sources surrounded by a *Pinus contorta* forest in the Rocky Mountain House area of Alberta, Canada, presented a hitherto unapproached problem of sampling and data analysis. This project was undertaken to: 1) determine if the IAP method could be used effectively in an area where a central lichen desert had not yet formed, 2) determine if alternative methods such as ordination and cluster analysis could be used in lichen biomonitoring problems, 3) design sampling techniques which could be effectively utilized for sampling epiphytes in coniferous forests, and 4) determine the extent of damage to the epiphytic lichen flora around the Aquitaine Ram River and Gulf-Strachan gas plants.

STUDY AREA

The study area is on the western edge of the foothills area of the eastern slope of the Rocky Mountains (Figs. 17 and 23). The flora and vegetation of the area are transitional between the Upper and Lower

Foothills Regions of Rowe (1972), although most of the plots sampled were in the former. The topography is rolling, with low to high, rounded hills and very few rock outcrops (Fig. 17). To the immediate west in the higher rounded hills, calcareous rock is exposed. Most plots used in the study were located at about 1120-1220 m elevation, in a forest dominated by *Pinus contorta* var. *latifolia* (Fig. 18). Many stands had small numbers of *Populus tremuloides*, *P. balsamifera*, and *Picea glauca*. Because of their sporadic occurrence, these species were not sampled.

The climate of the area is boreal cold temperate with cold winters and short, cool summers. During May-September the mean temperature and total precipitation at Prairie Creek Ranger Station are 0°C and 43 cm respectively. Total annual precipitation is 66 cm (mean 1971-72, Prairie Creek Station).

METHODS

A general reconnaissance of the upland vegetation in the Prairie Creek Region was conducted by several members of the Alberta Forest Service, and stands of *Pinus contorta* were selected for study around the Gulf-Strachan and Aquitaine Ram River Gas Plants. Twenty-one stands (including three control stands) in the vicinity of the two gas plants were utilized.

Pinus contorta var. *latifolia* Engelm. was the dominant tree in all of these stands, and the epiphytic lichens on that species were used in the study. Due to the flakey nature of the bark, *Pinus contorta* usually displays a depauperate corticolous lichen flora. In the Rocky Mountain House area, some lichens grew on the trunks of the pines, but the flora on the lower, dead branches appeared to be decidedly richer and better developed. Important species such as *Cetraria halei*, *Alectoria glabra*, *Hypogymnia physodes*, and *Usnea alpina* were always most numerous and luxuriant on the branches.

SAMPLING

A baseline was laid out through the center of a stand and the first 10 trees (*Pinus contorta* with diameter at breast height 13-21 cm) occurring within a band 4 m wide along the baseline were selected. Three

branches were collected from each tree, 30 per stand, from between 1 and 2 m above the ground. Each branch was considered as one quadrat and ranged in length from 60 to 100 cm and in diameter from 1 to 2 cm. Collections were made at the bases of the trees and on other substrates as well in order to ensure a complete sampling of lichen species. Voucher specimens are deposited in the University of Alberta Herbarium (ALTA).

The relative density and relative luxuriance of each lichen species present in each branch quadrat were rated on scales of one to five. Each species was considered independent of the others. For example, it was possible for each species on a given branch to receive a density rating of five. Relative density was determined by dividing each branch into five sections. A species that occurred on two sections of a branch received a rating of two. If a species occurred mainly on two sections but was also very scantily represented by a minute thallus on a third section, the rating was still two.

The assessment of relative luxuriance or development was based on size of the lobes and thalli, general appearance (very typical vs. discolored or otherwise moribund), and sometimes fertility. Fertility was considered important only in *Hypogymnia physodes*, which is usually sterile. Five to 10 percent of the specimens of *H. physodes* were fertile as well as robust and were considered to be very well developed (rating of five). *Cetraria halei* was almost always fertile. A specimen that was sterile, small (1-2 cm broad), and was discolored or fragmentary was rated at one. Specimens that were up to 5-6 cm broad, had apothecia almost 1 cm broad, and generally looked good were rated at five. Medium-sized, healthy looking specimens were rated at three. Ratings of two and four were given to specimens intermediate between one and three and three and five respectively. Other important species (*Alectoria glabra, Parmelia sulcata, Usnea* spp.) were always sterile. These were rated according to size and appearance similar to the method used for *Cetraria halei*. Characters such as size or fertility could vary within the range of a given species, so only specimens found in the study area were used to

judge "optimum" development. *Alectoria glabra* attains a length of up to 20 cm in the study area. Individuals only 1 cm long were found in some stands adjacent to the gas plants (rating of one). The same was true for *Usnea alpina*. Only fertile crustose lichens were considered in the study. Relative density was determined as explained above. The usual value was one. Little could be said about development of such species as *Lecanora varia*, because only scattered apothecia were found, and as such they appear much the same from branch to branch and were rated at one. Thus the crustose lichens, which can be considered of much less value than macrolichens in pollution studies, were usually rated only as present or absent.

Relative luxuriance-relative density values were derived for every species for each stand by multiplying the density rating by the luxuriance rating for a species on each branch or quadrat (a possible total of 30 quadrats per species per stand). These numbers were then summed and divided by 30. The resulting number was multiplied by 10 to get a larger, more workable number.

$$LD \text{ species } j = \Sigma \frac{(L_j D_j)}{N} \quad 10$$

where

LD = Luxuriance-density value for species j.

L = Relative luxuriance value on a scale of 1-5.

D = Relative density value on a scale of 1-5.

N = N of quadrat sampled.

The LD values of all species in a given plot were summed, resulting in a total LD value for each stand.

DATA PROCESSING

The stands were ordinated using the Bray and Curtis (1957) technique, Beals' (1960) equations for axis distances, and Sørenson's (1948) coefficient of community similarity. The ordination was based on the LD values obtained by the method outlined above.

Cluster analysis, a polythetic, agglomerative, hierarchial technique (Pritchard and Anderson 1971) was performed using the LD values. The following techniques of cluster analysis were used: nearest neighbor, farthest neighbor, group average, centroid clustering, and minimum variance, with minimum variance giving the best fit to the data.

RESULTS

In the study area, lichens are not common on the trunks of trees except at the base. However, a rich epiphytic lichen flora is present on the lower, often decorticated branches of the pines as well as on *Picea glauca* branches (Figs. 19, 21). From a quantitative analysis of 30 branches taken from 10 trees in each of 21 stands, 32 species of lichens were recorded (Table 1). Of these, 34% were fruticose, 41% were foliose, and 25% were crustose. The number of species found in a stand ranged from 7 to 22, with a mean of 15.8

The lichen floras on the basal 30 cm of the pine trees were remarkably similar to each other. *Cetraria pinastri* and *Parmeliopsis ambigua* occurred on nearly every tree base. *Alectoria glabra, Hypogymnia physodes, Usnea* species, and squamules of *Cladonia* were also common in this habitat. It seems that the basal portion of the pine provides a somewhat protected and uniform habitat. In all probability the epiphytes are less exposed to changes in humidity, wind speed, wind-blown SO_2, and minor changes in temperature. As well, they are covered by snow 6-7 months of the year. We feel that, at least in pine-dominated vegetation, lichens inhabiting the lowermost 30 cm of the trunks are not of much use as monitors of pollution.

Of the 32 species of lichens found on the lower branches of *Pinus*, 7 are very common in the control stands and are important components of the epiphytic vegetation (refer to Fig. 11 and Table 1 for stand locations and details of LD values):

Table 1. List of species collected in the 21 stands with their LD value for each stand arranged in order of decreasing LD values. Species diversity measurements in terms of Simpson's index, Equitability index, and No. of species are also given.
* = <1 LD value.

	14	17	26	22	12	24	23	3	11	19	6	8	18	5	21	1	10	7	2	9	4
Alectoria fremontii									1	1											
Alectoria glabra	41	41	29	47	71	27	33	21	28	25	30	20	26	17	12	31	16	14	15	13	7
Catillaria globulosa	1											1									
Cetraria chlorophylla						1									*						
Cetraria halei	54	69	28	11	*	27	23	21	16	8	17	23	9	20	19	6	26	16	3	8	*
Cetraria merrillii	5	1	6	3	39	2	2	5	1	5	5	3	9	2	*	5	4	*	2	2	3
Cetraria pinastri	1	1			*			*		1	1	1	*					*	1	*	
Evernia mesomorpha	6	4	1	2		1		1		1	2	1	1			1	2	1	1	1	
Hypogymnia vesterodes	2	9	21	4	6	6	2	2	1	4	2	1	3	7	7	2	3	3	1	1	
Hypogymnia physodes	25	22	29	25	2	18	16	17	8	18	8	16	7	9	12	10	10	9	7	5	*
Hypogymnia tubulosa						*															
Lecanora cadubriae	10	4	4	7	14	4	8	9	3	8	6	4	9	4	2	4	6	6	8	5	1
Lecanora collocarpa	2		*			1		1	*	1				1	*				1	*	
Lecanora varia	12	*	2	5	21	3	3	3	3	7	5	3	9	6	4	*	2	3	8	7	
Lecidea symicta		2						3		1		*		1							
Lecidea turgidula	2	2	1	2	4	4	4	4	1	2	5	2	5	5	3	3	2	1	5		
Letharia vulpina	2	*			1		*		*	*	*		*			*	1				
Parmelia cf. exasperata						*													*		
Parmelia exasperatula																					
Parmelia sulcata	17	16	30	20		13	7	10	9	6	6	4	3	7	19	5	3	7	3	3	1
Parmeliopsis aleurites	1		2			*		2		1			1	1			1				
Parmeliopsis ambigua	2	1		*		1		1	2	1	1	1	1	2	2		1		1		
Parmeliopsis hyperopta									1												
Ramalina minuscula	*	*								*											
Rinodina archaea										*											
Rinodina exigua																					
Usnea alpina	28	37	31	10	2	4	3	7	21	4	11	7	2	7		8	3	3	4		
Usnea dasypoga			5								1										
Usnea hirta		*															*				
Usnea scabrata	1																				
Usnea sorediifera	19	26	21	3		7	4	14	5	13	6	20	14	10	13	5	9	4	5	12	
Usnea subfloridana	32	15	12	40	14	15	23	6	28	5	8	1	4	2	2	14	1	11	7		3
LD Sum	264	247	222	180	174	132	127	127	125	114	114	108	103	101	97	94	90	80	73	57	15
No. of Species	21	19	16	14	12	19	13	18	17	22	17	17	17	16	14	14	17	14	17	13	7
Simpson's Index	.11	.15	.11	.16	.24	.13	.16	.11	.15	.11	.13	.15	.13	.11	.13	.17	.15	.12	.11	.15	.31
Equitability Index	9.9	8.2	8.1	7.0	6.0	10.0	6.5	9.9	8.8	11.7	8.7	9.2	9.0	10.8	8.5	7.1	9.0	8.9	10.3	7.6	5.2
Effect of Pollution on lichens	← NONE →				← SLIGHT →				← MODERATE →									← SEVERE →			

Alectoria glabra Mot. This species and *Cetraria halei* are the most common lichens on *Pinus* in the area. *Alectoria glabra* is common throughout the foothills and boreal forest of Alberta. It had the highest LD value of any species (71 at stand 12) and a mean LD value of 50 on the three stands most distant from the gas plants (Fig. 15). The LD values were 30 and 47 at two intermediate stands and averaged 23 in the remaining stands (Fig. 15). *Alectoria glabra* appears to be quite sensitive to air pollution. It often reaches a length of 20 cm, but near the gas plants individuals are poorly developed, less numerous, and seem to be dying out.

Cetraria halei W. Culb. & C. Culb. This species is generally very common in the Rocky Mountain House area and occurs throughout the foothills and boreal forest of Alberta. Specimens from near the gas plants are clearly moribund, and the number of individuals is reduced, with only one individual found at stand 4. In addition, its near absence at the distant stand 12 is most interesting. This is a young stand and the branches are heavily dominated by *Alectoria glabra* with *Cetraria merrillii* also common. The dominance of *A. glabra* probably represents a successional stage, which, in part, could account for its high LD value and for the rarity of *C. halei* and *Hypogymnia physodes* and the absence of *Parmelia sulcata*.

Hypogymnia physodes (L.) W. Wats. This species is best developed on logs, but is is also common on branches. It had the highest LD values at distant or intermediate stands (29, 25). Near the plants it was reduced in size and numbers and was almost absent at stand 4.

Parmelia sulcata Tayl. This widespread species is the most common *Parmelia* on conifers in Alberta. The best specimens were on larger branches in intermediate or distant stands. It was very poorly represented in stands 4, 9, 2, and 1, and most individuals in stand 22 were moribund.

Usnea alpina Mot. This appears to be a very sensitive species to SO_2 pollution. Robust specimens were found at stands 14, 17, and 26. It was absent at stands 4 and 9 and was rare and poorly developed near the gas plants.

Usnea sorediifera (Arn.) Lynge. This species and *U. subfloridana* are very common on pine branches in the area. They had the highest LD values at distant or intermediate stands, but were still fairly abundant on the stands adjacent to the gas plants. The individuals in these adjacent stands, however, were much reduced in size and appeared to be dying out.

Twenty-five other species were found on the pine branches studied. Brief comments on these and on some additional species found in general collections follow:

Alectoria fremontii Tuck. Found only at stands 11 and 19. This species is more common on *Picea* in the area.

Bacidia sphaeroides (Dicks.) Zahlbr. Found once at the base of *Populus balsamifera* in stand 11.

Caloplaca cerina (Ehrh.) Th. Fr. On *Populus balsamifera* in stand 21.

Caloplaca holocarpa (Hoffm.) Wade. On *Populus balsamifera* in stand 21.

Catillaria globulosa (Flörke) Th. Fr. On pine branches in stands 8 and 14.

Cetraria chlorophylla (Willd.) Vain. Not common; found on *Pinus* in stands 21 and 24.

Cetraria cucullata (Bell.) Ach. This is a terricolous, arctic-alpine species that would not be expected on trees. A few thalli were found at the base of *Pinus* in stand 26.

Cetraria merrillii Du Rietz. This inconspicuous species was found on pine branches in every stand. It was most abundant in a young pine stand with *Alectoria glabra* at stand 12.

Cetraria pinastri (Scop.) S. Gray. Occasional on pine branches and very common at the bases.

Cladonia arbuscula (Wallr.) Rabenh. On the ground, especially in open pine stands.

Cladonia verticillata (Hoffm.) Schaer. On logs and stumps.

Evernia mesomorpha Nyl. This species was found in most stands, but it was never common. The best specimens were from stands 14 and 17.

Hypogymnia austerodes (Nyl.) Räs). This species was found in all stands except 4. It was most common on logs and large branches.

Hypogymnia tubulosa (Schaer.) Hav. Rare, found on *Pinus* in stand 24.

Lecania dimera (Nyl.) Th. Fr. New to Alberta. Found on *Populus balsamifera* at stand 21. Skorepa 9039 (ALTA).

Lecanora cadubriae (Mass.) Hedl. A common species on pine branches.

Lecanora coilocarpa (Ach.) Nyl. Fairly common on pine branches.

Lecanora hagenii (Ach.) Ach. Found on *Populus balsamifera* at stand 21.

Lecanora varia (Ehrh.) Ach. Common on pine branches.

Lecidea scalaris (Ach.) Ach. On a burnt stump at stand 24.

Lecidea symmicta (Ach.) Ach. Found a few times on pine branches.

Lecidea turgidula Fr. Found on pines in all stands except 4 and 9.

Letharia vulpina (L.) Hue. Not common in the area. The best specimens were found at stand 14; it was absent from stands near the plants.

Parmelia cf. *exasperata* De Not. Found on *Pinus* only at stand 24.

Parmelia exasperatula Nyl. On pines at stand 2.

Parmeliopsis aleurites (Ach.) Nyl. Occasional on branches, but most common on logs.

Parmeliopsis ambigua (Wulf.) Nyl. Very common on logs and at the base of pines, although found a few times on branches in most stands.

Parmeliopsis hyperopta (Ach.) Arn. Not common in this area; found mostly on logs.

Peltigera aphthosa (L.) Willd. Common on the ground and over bryophytes.

Peltigera venosa (L.) Baumg. On the ground in stand 12.

Platismatia glauca (L.) W. Culb. & C. Culb. Found a few times on pines.

Ramalina minuscula (Nyl.) Nyl. Found only in stands 14 and 17 on pines.

Rinodina archaea (Ach.) Arn. On *Pinus* in stand 19.

Rinodina exigua (Ach.) S. Gray. On *Pinus* in stand 19.

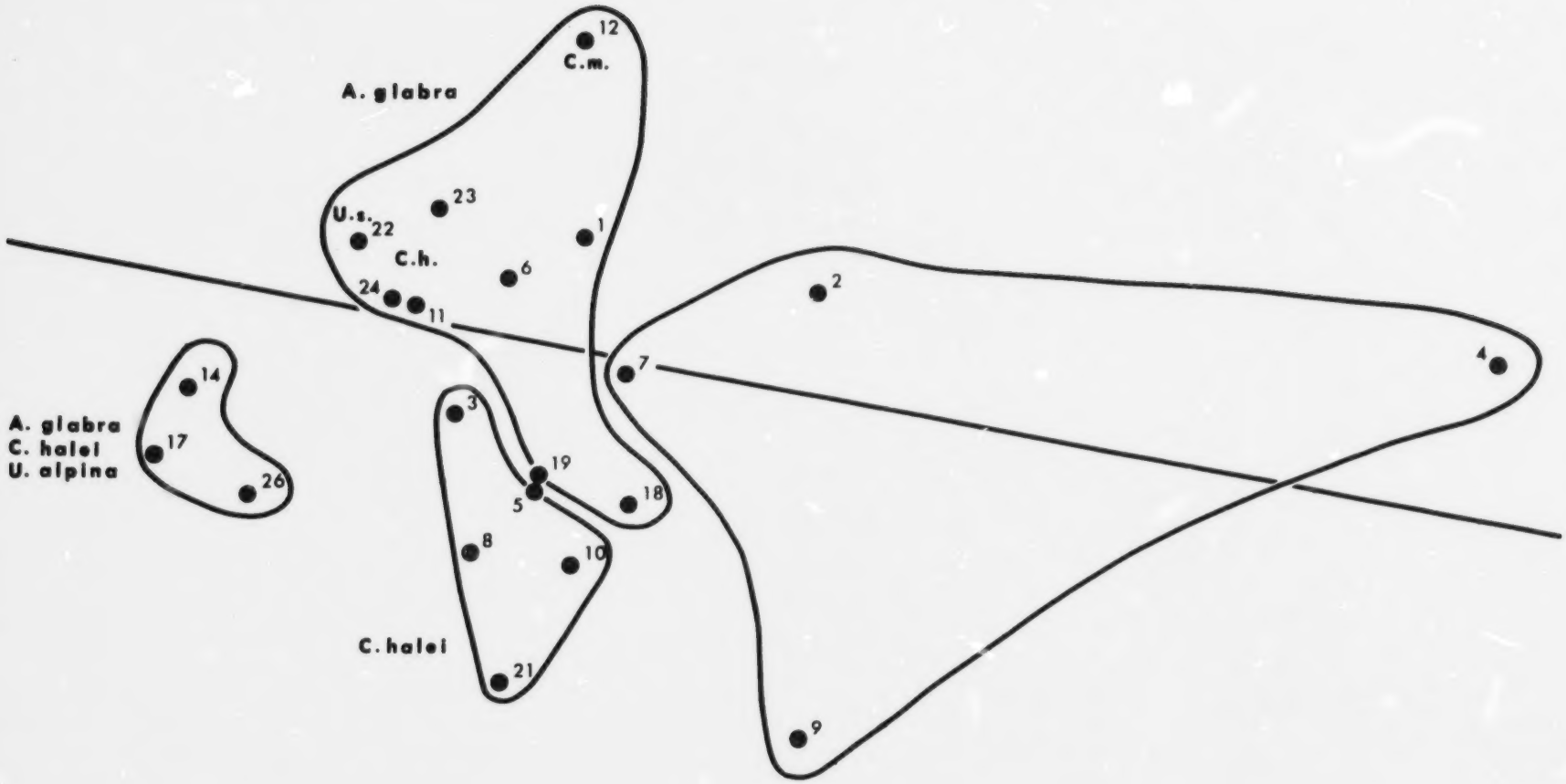
Usnea dasypoga (Ach.) Röhl. On pines in stands 6 and 26.

Usnea hirta (L.) Wigg. On pines in stands 10 and 17.

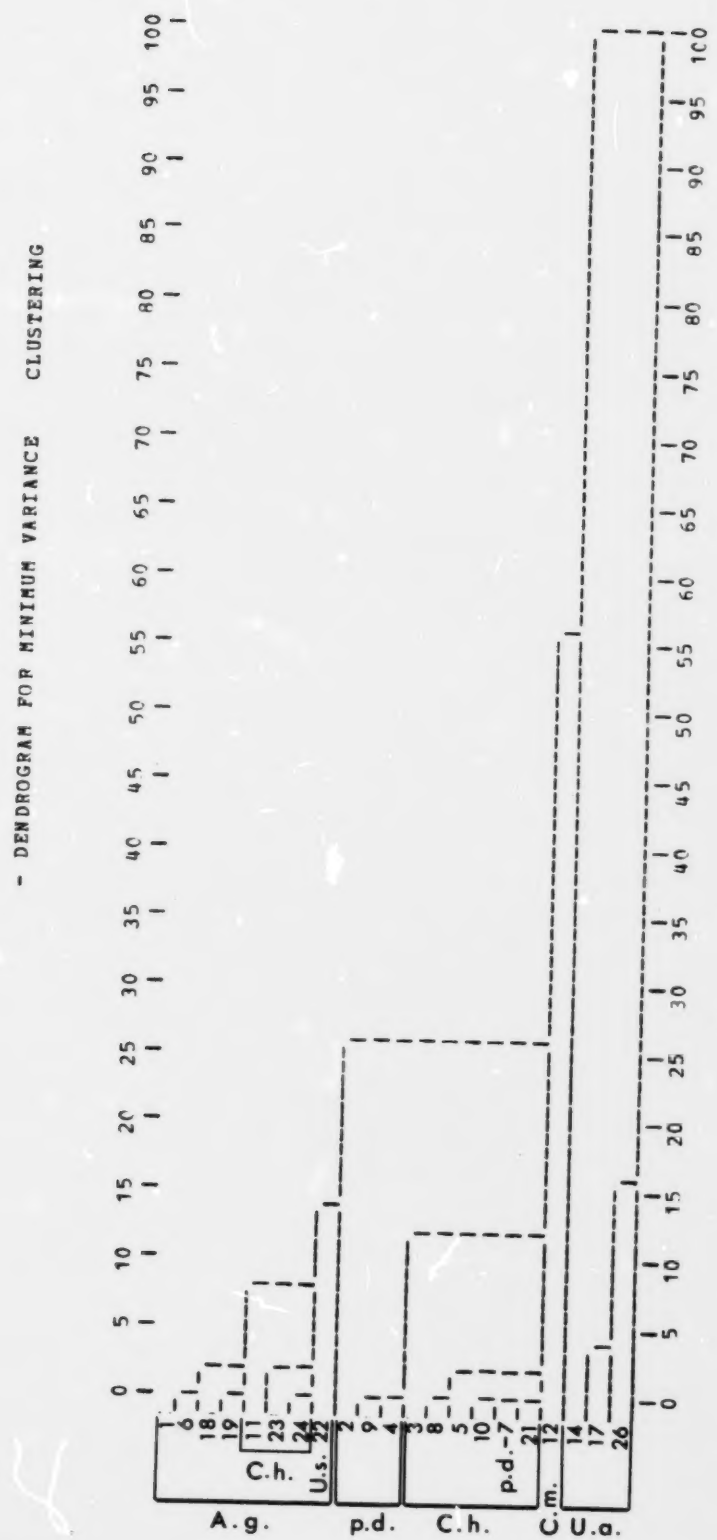
Usnea scabrata Nyl. Found only in stand 14.

An analysis of the data indicates that four associations of lichen species can be recognized in the area surrounding the two gas plants. One of these appears to represent the natural epiphytic lichen vegetation present on pine branches in the area and three are representative of associations which have been affected by SO_2 pollution to a varying extent. In the vegetation surrounding the sources of SO_2 pollution there is a gradient of the dominant lichen species outward. This gradient is particularly apparent when considered in the quantitative terms of luxuriance and density. The two-dimensional ordination is shown in Fig. 1, illustrating the pattern of distribution of the lichen associations. Even though the ordination was constructed solely from dissimilarity values between sampled stands, the stand groupings often indicate environmental gradients important to lichen vegetation. It seems that the horizontal axis of the ordination represents the effect of accumulated SO_2 pollution on the lichen vegetation, with stands usually nearest and most heavily affected to the right, and unaffected control stands to the left. In addition, those stands to the left have the highest LD values and those to the right have the lowest (Fig. 3). (This is further discussed below). The cluster analysis (Fig. 2) distinguishes associations similar to those of the ordination, while some of the differences are pointed out below.

Species diversity indices show little difference between the associations and individual stands (Table 1). If the stands are divided into two groups, those unaffected (control) or slightly affected by SO_2 pollution -- 9 stands to the left in Table 1 -- and those moderately or severely affected (12 stands), few differences in species diversity indices are found. For example, using Simpson's Index for dominance concentration, mean values of 0.15 are recorded for both groups, while with the Equitability Index (Whittaker 1972) for equitability, mean values of 8.3 for slightly affected areas vs. 8.8 for moderately to severely affected areas are obtained. The mean number of species found in the two groups is 16.6 for the former and 15.3 for the latter, again indicating no significant differences. However, the mean LD values for the two groups indicate significant differences in lichen growth and abundance. The control and slightly affected stands have a mean value of 178, while the moderately to severely affected stands have a mean value of 87.


12
C.m.
A. glabra
23
U.s.
22
C.h.
1
6
24
11
2
4
7
14
A. glabra
C. halei
U. alpina
17
26
3
19
5
18
8
10
C. halei
21
9

(1)


- DENDROGRAM FOR MINIMUM VARIANCE CLUSTERING
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
6 18 19 11 23 24 22 2 9 4 3 8 5 10 7 21 12 14 17 26
C.h. U.s. p.d. p.d. C.h. C. m. U.a.
A.g.

(2)

Usnea alpina -- Alectoria glabra -- Cetraria halei Association (Figs. 19, 21)

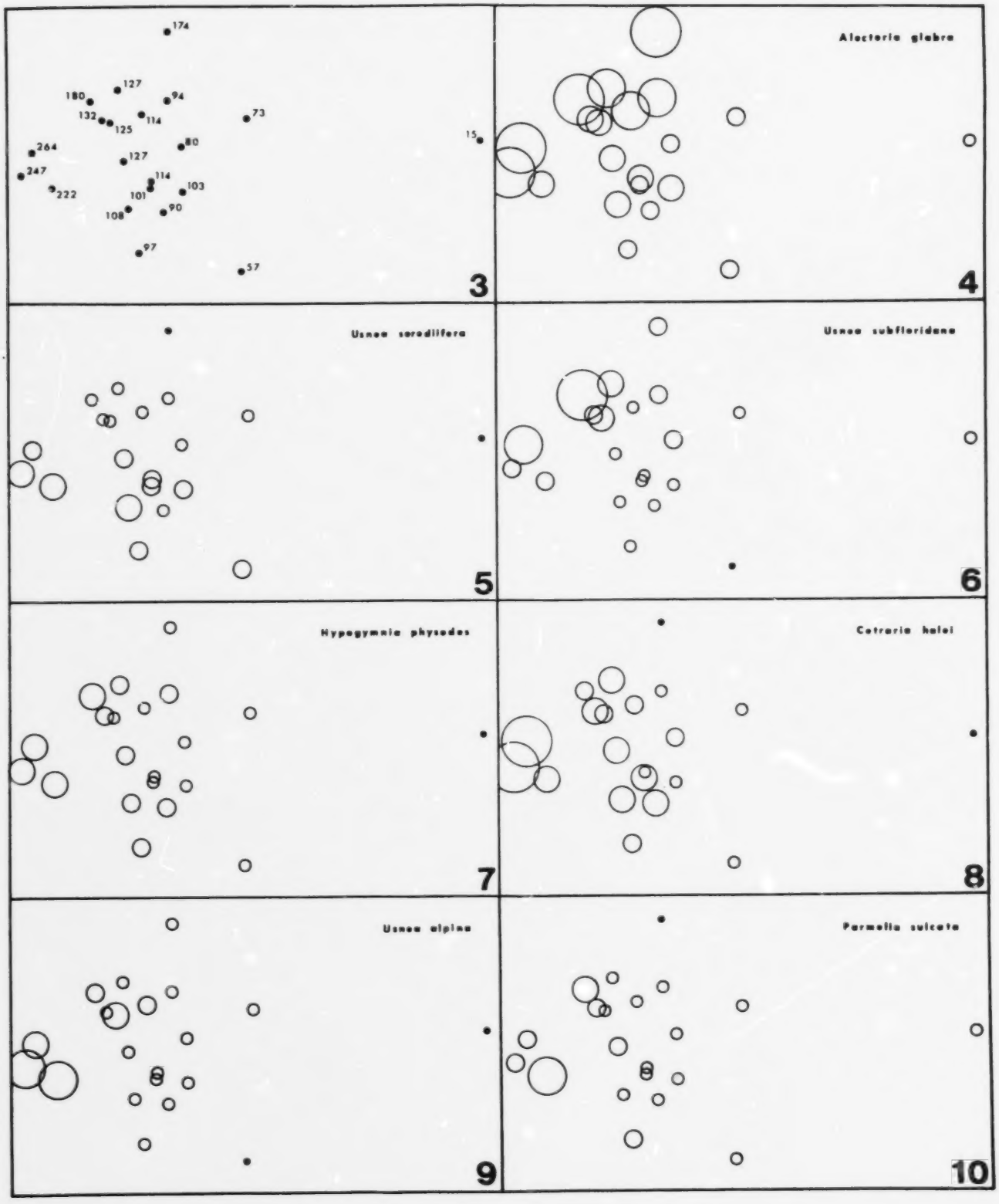
This association of species is characterized by a dominance of *Usnea alpina* (Fig. 9) and *Cetraria halei* (Fig. 8). These species are better developed in this association than in any other, while *Alectoria glabra* (Fig. 4) is important not only in this association, but in others as well. Also reaching their greatest luxuriance and density are *Hypogymnia physodes* (Fig. 7) and *Parmelia sulcata* (Fig. 10). The number of species per stand found in this association ranges between 16 and 21, and the mean LD value is 244 with a range of 222 to 264. This association probably closely approximates the natural epiphytic lichen vegetation in the study area in mesic, mixed *Pinus-Picea* forests. As far as we can tell, these "control" stands have not been affected by SO_2 pollution from the sources considered in our study, and the LD value of 244 can be considered as an approximation of the expected normal value for lichen vegetation in the study area.

Alectoria glabra Association (Fig. 22)

Represented on the ordination (Fig. 1) by nine stands, this association appears to become prevalent when the lichen vegetation is slightly affected by SO_2 pollution. LD values range between 94 and 180, with a mean of 129, while species richness varies between 12 and 22 species per stand.

Species that are most sensitive to SO_2 pollution have been affected to the point that they are depauperate and less abundant in this association. Thus, *Usnea alpina* (Fig. 9), *Parmelia sulcata* (Fig. 10), and *Hypogymnia physodes* (Fig. 7) are somewhat reduced in luxuriance and density, leaving, in many of the stands, a dominance of *Alectoria glabra* (Fig. 4).

The vertical axis of the ordination (Fig. 1) illustrates a second set of parameters. Oriented along this vertical axis is the *Alectoria glabra* association at the top and the *Cetraria halei* association near the bottom. Although we have no measurements of physical parameters to superimpose on the ordination, we would estimate that the important factor is age of the stand, which in turn, often correlates with drier, lighter


174
127
180
94
132
114
125
73
15
264
80
127
247
114
222
101
103
108
90
97
57
3
Alectoria glabra
4
Usnea sorediifera
5
Usnea subfloridana
6
Hypogymnia physodes
7
Cetraria halei
8
Usnea alpina
9
Parmelia sulcata
10

Figs. 3 to 10. Importance of the seven major lichen species plotted over stand position on the two-dimensional ordination. A solid dot indicates absence in the stand. Circle size indicates LD value for species in a stand. Circle sizes from smallest to largest equal LD values of 1-9, 10-19, 20-24, 30-39, > 40. Figure 3 gives the patterning of stands and the total LD values for each stand as positioned by the ordination.

conditions in young stands, while older, more mature stands are more mesic, shaded, and usually contain a mixture of white spruce and pine. *Alectoria glabra,* along with *Usnea subfloridana* (Fig. 6), appears to prefer the former, while *Cetraria halei* and *Usnea sorediifera* prefer the older, mixed stands.

The cluster analysis (Fig. 2) separates from the *Alectoria glabra* association two stands which are distinctive due to the predominance of one particular species. Stand 22 contains an unusually large amount of *Usnea subfloridana,* while stand 12 contains a dominance of *Cetraria merrillii.* This latter stand, located at Ram Falls, is a young, xeric stand which is somewhat different than the other stands sampled. Stands 24 and 11 (Figs. 1-2) are transitional to the *Cetraria halei* association.

Cetraria halei Association

The five stands dominated by *Cetraria halei* occur in more mesic sites which are moderately affected by SO_2 pollution. The pollution is severe enough to restrict growth of the more sensitive species. In most cases, such species as *Usnea alpina, Alectoria glabra,* and *Usnea subfloridana* (see Table 1 for others) are not totally lacking; rather, they are depauperate and often occur only occasionally. *Cetraria halei* still persists in large numbers, however, resulting in its higher LD values. The mean LD value is 105 with the range 90-127, while the species richness varies between 14 and 17.

Association No. IV

(Fig. 20)

This association occurs in areas where the lichen vegetation is severely affected by SO_2 pollution. No particular species are dominant; instead, the association is characterized by a lack of dominant species. The mean LD value is 56, ranging between 15 and 80. The species richness varies between 7 and 17. This is not a lichen desert, probably because not enough time has elapsed since the pollution sources began operation.

DISCUSSION

One of the factors which is of importance in controlling lichen distribution is air pollution, in particular SO_2. The ordination graphically represents the relationship between luxuriance-density of the lichen

vegetation in relation to a SO_2 pollution gradient on the horizontal axis and to a combination of parameters including age of stand, light, and moisture on the vertical axis.

Each species of lichen has a particular tolerance to SO_2 pollution and thus each drops out of the dominance structure of the vegetation at a different rate. It seems from our data that if only the dominant species are considered, *Usnea alpina* is most sensitive, followed by *Usnea subfloridana*, *Alectoria glabra*, and *Cetraria halei*. These species seldom disappeared from a stand, since the pollution was recent; instead, they became depauperate and appear to be dying out.

The LD values form a gradient ranging from 15 in areas severely affected by SO_2 pollution to values between 222-264 in control stands or stands not affected by the pollution. Figure 11 shows the relationship of the sampled stands (circles) to the two gas plants (squares). The LD values are reduced to a scale of 1-5 in Fig. 12 (i.e.: 0-90 = 1, 91-125 = 2, 126-175 = 3, 176-225 = 4, and > 226 = 5). These are then plotted on Fig. 12 over the stand positioning. The control stands 12, 14, and 17 have values of 4, 5, and 5, respectively, and all are located more than 24 km from the gas plants. As one approaches the sources of pollution, the values decrease markedly, until in the immediate vicinity of the gas plants, values of 1 are obtained. We believe that values between 1 and 2 (or an LD value of less than 125) indicate moderate to fairly severe effects of SO_2 on the lichen vegetation, while values of 3 and 4 indicate little or sometimes no damage to the lichen flora.

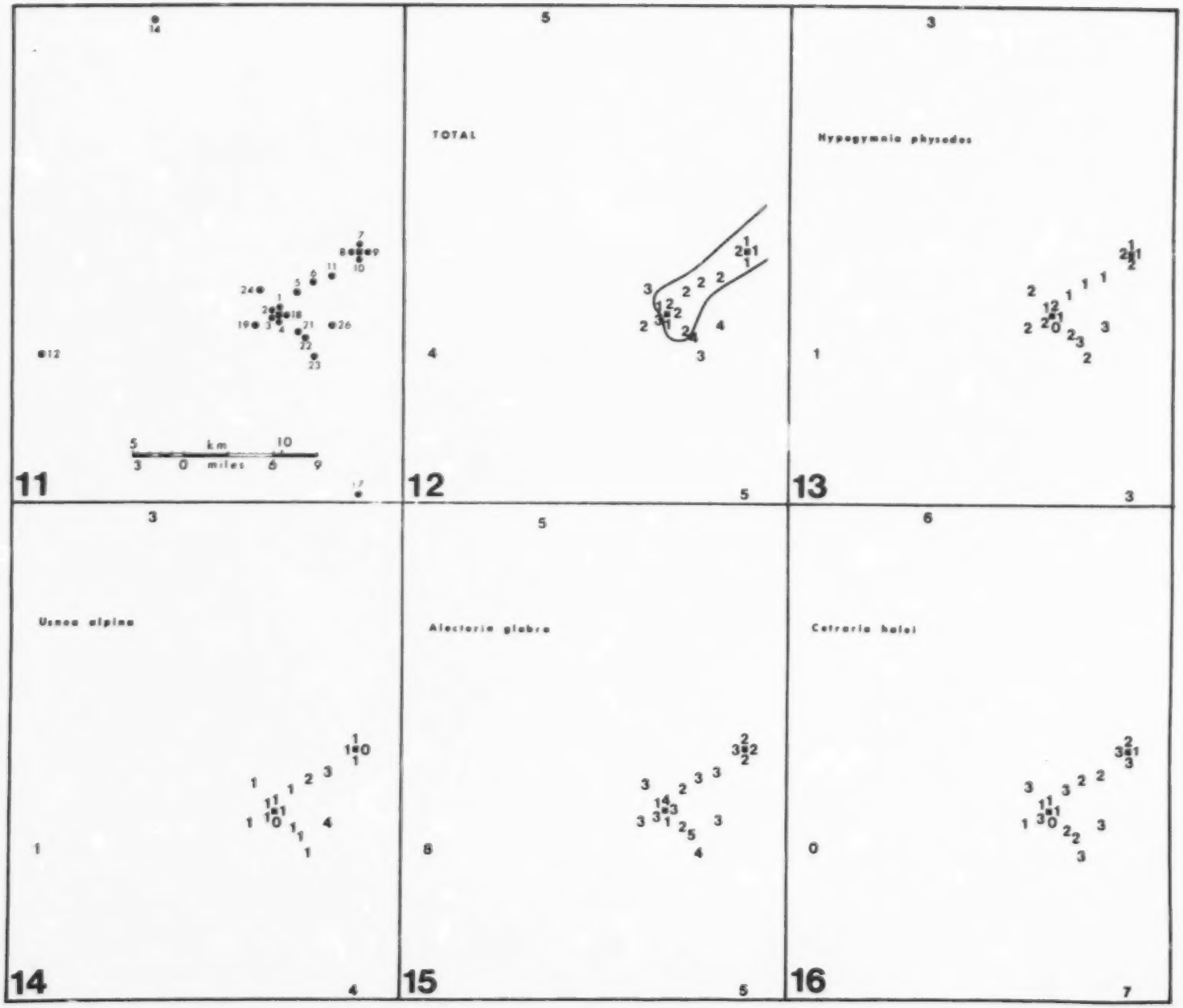
Figures 13-16 are plots of the most important individual species and show the marked decrease from control conditions to severely affected areas in such species as *Usnea alpina*, *Cetraria halei*, *Alectoria glabra*, and *Hypogymnia physodes*. In all probability, by use of the LD index for these four species, valid estimates of pollution effects can be made, once a control reference is established.

In relation to the above, the four lichen associations have distinct zones of occurrence around the gas plants. For example, the *Cetraria halei* association is found closer to the gas plants than is the

Fig. 11. Positioning of stands (as circles) in relation to the two gas plants (as squares), with stand number indicated.

Fig. 12. Positioning of stands in relation to gas plants (squares) with numbers indicating total LD values for each stand on a scale of 1 to 5, i.e.: 1 = 0-90, 2 = 91-125, 3 = 126-175, 4 = 176-225, and 5 = > 225. Solid line gives estimated area of severe damage to lichen vegetation.

Figs. 13 to 16. Positioning of stands in relation to gas plants (squares) with numbers indicating LD values for five individual species on a scale of 1 to 8, i.e.: 1 = 0-9, 2 = 10-19, 3 = 20-29, 4 = 30-39, 5 = 40-49, 6 = 50-59, 7 = 60-69, 8 = 70-79.


11
12
TOTAL
13
Hypogymnia physodes
14
Usnea alpina
15
Alectoria glabra
16
Cetraria halei
5 km 10
3 0 miles 6 9

Alectoria glabra association. The former contains stands with an LD on the 1-5 scale of 1,2,2,2, and 3; while the latter contains stands with 2,2,2,2,2,3,4, and 4.

COMPARISON OF IAP AND LD INDEX

The IAP (Le Blanc and DeSloover 1970) was calculated in the traditional manner. There is little correlation of the IAP with the LD index. The IAP is basically an expression of the number of species in a given stand. This is often a significant factor around established sources of pollution. In such cases, lichen floras are known to become depauperate or entirely absent, giving rise to lichen deserts.

With increasing distance from a source of pollution, number of species, luxuriance, and density of lichens increase. However, around more recent pollution sources, luxuriance and density of the lichen vegetation may significantly decrease while species richness remains stable. In such areas of incipient pollution (or in air pollution monitoring studies) the IAP may be of little value.

A lichen desert or zone of lichen absence has not (yet) developed in our study area. There is no distinct increase in the number of species at increasing distances from the gas plants. For example, stands 14 and 19 (Fig. 11) have nearly the same species richness (21 and 22 species respectively) and similar IAP values (77 and 74 respectively); however, they are not similar based on the LD index -- 264 at 14 and 114 at 19. This is because the LD considers luxuriance of the various species: *Alectoria glabra, Cetraria halei, Hypogymnia physodes, Parmelia sulcata* and *Usnea* spp. have higher LD values at stand 14. The high IAP of stand 19 results from the presence of some species that are rare in the entire region, including stand 14.

The mean number of species is 16, with a range from 13 to 19, except for stand 4 with 7 species and stands 14 and 19 with 21 and 22 species respectively. The IAP for these stands is similar, with most of the values in the 50's. Stands with the lowest number of species tend to have the lowest IAP. Ram Falls (stand 12) for instance, has a rich lichen growth, but few species (12). It has an IAP of 48 but an LD of 174. So the IAP is mostly

Fig. 17. View of the general topography and vegetation in the study area. Picture taken just south of Aquitaine Gas Plant. In valley a *Betula glandulifera* fen surrounded by *Picea mariana* with *Pinus contorta*, *Picea glauca*, and *Populus tremuloides* (light color) on the hillside.

Fig. 18. View of stand No. 1, just north of Aquitaine Gas Plant with a mixed stand of *Pinus contorta*, *Picea glauca*, and a few *Populus tremuloides*.

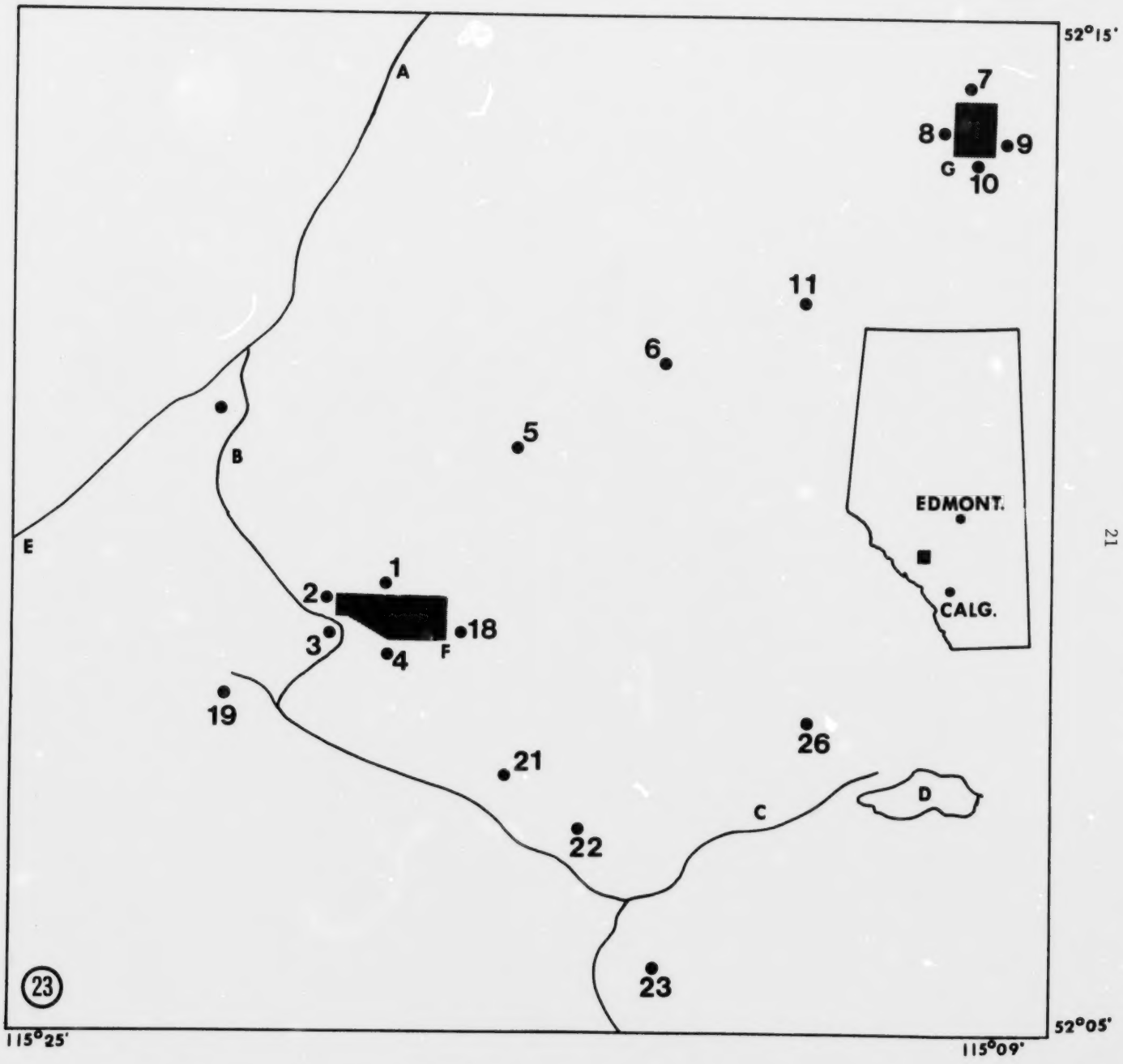
Fig. 19. A branch of *Pinus contorta* from a control stand, with luxuriant and abundant thalli of *Usnea alpina*, *Alectoria glabra*, *Cetraria halei*, and *Parmelia sulcata*.

Fig. 20. A branch of *Pinus contorta* from stand No. 2, with depauperate thalli of *Alectoria glabra*, *Usnea* spp., and *Parmelia sulcata*.

Fig. 21. Closeup of branch in Fig. 19 showing well-developed thalli.

Fig. 22. Closeup of branch in Fig. 19 with healthy thalli of *Usnea alpina*, *Cetraria halei*, and *Alectoria glabra*.

Fig. 23. Map of the study area located southwest of Rocky Mountain House. Roads shown by solid black lines. Important place names include: (A) Prairie Creek Road from Rocky Mountain House; (B) Road to Aquitaine Ram River Gas Plant; (C) Road to Swan Lake; (D) Swan Lake; (E) Road to Forestry Trunk Road; (F) Aquitaine Ram River Gas Processing Plant, and (G) Gulf-Strachan Gas Processing Plant. Stands sampled are numbered 1-26; the three control stands are off the map.


52°15'
A
7
8
9
G
10
11
6
5
B
EDMONT.
E
1
2
18
3
4
F
CALG.
19
26
21
D
C
22
23
(23)
115°25'
52°05'
115°09'

determined by the number of species per stand as well as the frequency-coverage of each species. The occurrence of a few uncommon species in any of our stands would raise the IAP, which would be meaningless since complete floras persist in most of the stands. The additional species would simply be rare, not absent from some zones due to pollution.

Computing the IAP with LD in place of f takes into account luxuriance as well as frequency-coverage and species richness, and is a more sensitive value than the IAP using f alone. The resulting IAP corresponds well to the LD because of our addition of luxuriance as a factor. Differences between stands 14 and 19 are clear (i.e. IAP 66 and 42 respectively), even though they have a similar number of species. This added weight from the consideration of luxuriance results in a better evaluation of the lichen flora at these stands. Stand 4 has the lowest values using all three methods; stand 9 was clearly second lowest using LD and LD in the IAP formula, but is similar to the other stands using f (similar number of species). The LD alone seems to be the most sensitive method. It displays a greater range of values throughout its scale. Using the LD in the IAP formula would work in our area, but again, it does not display differences as well as does the LD alone. The LD range was 15-264; that of the IAP was 11-66. The traditional IAP technique would not have demonstrated the differences in lichen floras that exist around Rocky Mountain House.

CONCLUSIONS

1) Methods of indirect gradient analysis (ordination) as well as cluster analysis are useful tools in organizing data in lichen biomonitoring problems.
2) Qualitative differences were observed between lichens in stands near the gas plants and those more distant. These differences were quantitatively analyzed using a scale which considered relative luxuriance and relative density of lichen species (LD index.)

3) These differences could not be illustrated using the traditional IAP, because the number of species per stand did not vary appreciably. The differences were quantitatively analyzed using the LD index. By using specific criteria in assigning luxuriance values for each taxon on each branch, we believe the subjectivity inherent in such work was mitigated. We believe this method is of particular value in studying the effects of air pollution around new sources of pollution.
4) The construction of a map using the LD values revealed areas of severe, moderate, and slight effects of SO_2 pollution on the lichen vegetation. From our data, we believe that values between 1 and 2 (see Fig. 12) (or an LD value of < 125) indicate moderate to fairly severe effects of SO_2 on the lichen vegetation, while values of 3 and 4 (LD values of 125-225) indicate little or sometimes no damage to the lichen flora.
5) Four lichen associations occur in the area surrounding the two gas plants studied. These occur in correlation to the effect of SO_2 pollution on the lichen vegetation, with the *Cetraria halei* association being more tolerant of SO_2 pollution than the *Alectoria glabra* association.
6) The most sensitive species appear to be *Alectoria glabra*, *Cetraria halei*, and *Usnea* spp. In cases where these persist near the gas plants, they are poorly developed and appear to be dying out. *Hypogymnia physodes* and *Parmelia sulcata* are also sensitive to SO_2 pollution in this area. Little can be determined about species such as *Evernia mesomorpha* and *Letharia vulpina*, because they are not very common in the sampled vegetation.
7) The construction of a biomonitoring map (Fig. 12) reveals that the lichen vegetation has been severely affected close to both gas plants. However, this zone of severe damage occurs only within 1.5-3 km of the plants. Stands between 3 and 10 km are only moderately affected and little damage is present in some of these stands.

At present, damage to the lichen vegetation occurs only in areas close to the plants; however, it appears that the lichens are gradually disappearing in stands farther from the plants and as time goes on, the severely affected areas will increase.

8) In the Rocky Mountain House area, the lichen component of the vegetation can effectively be utilized in analyzing the effects of SO_2 pollution on living organisms. The utilization of lichens in biomonitoring studies such as this one can have several advantages:
   a) The cost of a study using lichens as bio-indicators of air quality is not as expensive as the purchase and upkeep of air pollution monitoring equipment.
   b) As opposed to air monitoring equipment which shows only the concentration of the pollutants, lichens reflect the actual cumulative effects that the pollution is having on the ecosystem.
   c) Once a pilot study has been completed, the identification of the most important lichen species and the use of particular lichen associations to show levels of pollution can be accomplished by relatively unspecialized personnel.
   d) Lichens are the most sensitive component of the vegetation to SO_2 and other types of air pollution and as such can have predictive value in assessing future effects on the vascular plant vegetation.

ACKNOWLEDGMENTS

We wish to thank D. Hocking, Northern Forest Research Centre, Canadian Forestry Service, for his interest and suggestions toward this research, and J. Ridgway for assistance in the field. We are grateful to M. Ostafichuk and D.G. Horton for reading the manuscript. Support of this research was through contract QSUS-0148 from the Northern Forest Research Centre, Edmonton, Alberta, and from National Research Council of Canada grant A-6390, both to D.H. Vitt.

LITERATURE CITED

Beals, E. 1960. Forest bird communities in the Apostle Islands of Wisconsin. Wilson Bull. 72:156-181.

Bray, J.R. and J.T. Curtis. 1957. An ordination of upland forest communities of southern Wisconsin. Ecol. Monogr. 27:325-349.

Brodo, I.M. 1966. Lichen growth and cities: a study on Long Island, New York. Bryologist 69:427-449.

DeSloover, J. and F. LeBlanc. 1968. Mapping atmospheric pollution on the basis of lichen sensitivity. Pages 42-56 in R. Misra and B. Gopal eds. Proc. Symp. Recent Adv. Trop. Ecol. Varanasi, India.

Fenton, A.F. 1960. Lichens as indicators of atmospheric pollution. Ir. Nat. J. 13:153-159.

_____. 1964. Atmospheric pollution of Belfast and its relationship to the lichen flora. Ir. Nat. J. 14:237-245.

Ferry, B.W., M.S. Baddeley, and D.L. Hawksworth. 1973. Air pollution and lichens. Toronto.

Gilbert, O.L. 1965. Lichens as indicators of air pollution in the Tyne Valley. Pages 35-47 in G.T. Goodman, R.W. Edwards, and J.M. Lambert, eds. Ecology and the industrial society. Oxford Univ. Press, London and New York.

_____. 1970. A biological scale for the estimation of sulfur dioxide pollution. New Phytol. 69:629-634.

Hawksworth, D.L. and F. Rose. 1970. Qualitative scale for estimating sulphur dioxide air pollution in England and Wales using epiphytic lichens. Nature 227:145-148.

LeBlanc, F. and J. DeSloover. 1970. Relation between industrialization and the distribution and growth of epiphytic lichens and mosses in Montreal. Can. J. Bot. 48:1485-1496.

LeBlanc, F., D.N. Rao, and G. Comeau. 1972. The epiphytic vegetation of *Populus balsamifera* and its significance as an air pollution indicator in Sudbury, Ontario. Can. J. Bot. 50:519-528.

LeBlanc, F., G. Robitaille, and D.N. Rao. 1974. Biological response of lichens and bryophytes to environmental pollution in the Murdochville Copper Mine area, Quebec. J. Hattori Bot. Lab. 38:405-433.

Mathis, P.M. and G. Tomlinson. 1972. Lichens: Bioassay for air pollution in a metropolitan area (Nashville, Tennessee). J. Tenn. Acad. Sci. 47:67-73.

Nash, T.H. 1971. Lichen sensitivity to hydrogen fluoride. Bull. Torrey Bot. Club 98:103-106.

_____. 1972. Simplification of the Blue Mountain lichen communities near a zinc factory. Bryologist 75:315-324.

Nylander, W. 1866. Les lichens du jardin du Luxembourg. Bull. Soc. Bot. Fr. 13:364-372.

Pritchard, N.M. and A.J.B. Anderson. 1971. Observations on the use of cluster analysis in botany with an ecological example. J. Ecol. 59:727-747.

Rao, D.N. and F. LeBlanc. 1967. Influence of an iron-sintering plant on corticolous epiphytes in Wawa, Ontario. Bryologist 70:141-157.

Rowe, J.S. 1972. Forest regions of Canada. Dep. Environ., Can. For. Serv. Publ. 1300. Ottawa, Canada.

Skye, E. and I. Hallberg. 1969. Changes in the lichen flora following air pollution. Oikos 20:547-552.

Sørenson, T.A. 1948. A method of establishing groups of equal amplitude in plant sociology based on similarity of species content, and its application to analysis of the vegetation of Danish commons. Biol. Skr. K. Dan. Vidensk. Selsk. 5:1-34.

Whittaker, R.H. 1972. Evolution and measurement of species diversity. Taxon 21:213-251.